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METHOD FOR CALIBRATING THE CYLINDER SENSOR SUITE OF AN INTERNAL COMBUSTION ENGINE, IN PARTICULAR OF A MOTOR VEHICLE, OPERATED IN INDIVIDUAL-CYLINDER FASHION

Background Information

The invention concerns in general internal combustion engines, in particular of motor vehicles, operated in individual-cylinder fashion, and in particular a method for the calibration of sensors, disposed in at least two cylinders of such an internal combustion engine, for sensing a variable characterizing the combustion process in the respective cylinder, as defined in the preamble of independent Claim 1.

Internal combustion engines operated in individual-cylinder fashion often have a so-called fuel quantity compensation control system (FQCC) or smooth-running control system (SRC) which is evident, for example, from DE 199 45 618 A1. For this, a controller is associated with each cylinder of the internal combustion engine. The background for this action is that in the event of any quantity errors during fuel metering, an inherently undesirable torque nonuniformity occurs. If an increased quantity of fuel is metered to a cylinder as a result of tolerances, the FQCC causes a negative fuel quantity to be added to the operator-commanded quantity for that cylinder. Conversely, a positive fuel quantity is added when too small a fuel quantity is metered to a cylinder.

During operation of a diesel engine, by means of the two control systems (FQCC and SRC) any injection quantity errors that result in torque differences and thus in nonuniform

engine rotation speeds can be corrected, and engine smoothness at low rotation speeds -- which is known to be critical in diesel engines -- can be substantially improved. In addition, the equalization of the cylinders caused by the correction allows emissions improvements to be achieved not only in the lower rotation-speed range relevant to smoothness, but also at higher engine speeds.

A fuel quantity equalization by means of an FQCC or SRC is not efficient in all operating ranges of a diesel engine, however, since depending on the type of engine, additional effects occur such as torsional vibrations at the crankshaft, which moreover are highly dependent on rotation speed. Methods for individual-cylinder operation of an internal combustion engine have therefore also been proposed in which a direct evaluation is made of a signal (for example of the cylinder pressure) that is directly correlated with combustion. These methods allows cylinder equalization even at higher rotation speeds. In these methods, operating parameters of the combustion process, for example the mean pressure indicated in the individual cylinders or the torque corresponding thereto or the center point of the pressure difference between the individual cylinders, are calculated from the cylinder pressure profile. By regulating the indicated mean pressure, it is thus possible to achieve a more precise individual-cylinder regulation of the setpoint torques, and thus a better equalization of the cylinders in all operating ranges.

In cylinder-pressure-based engine control systems, the cylinder pressures occurring during operation of the engine are measured by means of pressure sensors over time or as a function of crank angle, and made available to an engine control system. A pressure sensor of this kind is evident, for example, from DE 197 49 814 A1. Also known are methods with which parameters can be ascertained during engine operation from a high-resolution pressure signal and are in turn used

for individual-cylinder optimization of the engine process in terms of the target variables of fuel economy, emissions, and smoothness. The parameters used are, for example, the pressure or pressure difference integrals, the indicated work, or the indicated torque.

Also disclosed, in the unpublished German patent application numbered 101 59 017, is a similar method in which open- and/or closed-loop control of engine operating parameters is accomplished as a function of a variable derived from the actual pressure signal. This derived variable characterizes, for example, the change in the pressure signal or the combustion profile. This enables a very accurate correction of preinjection during engine operation.

The aforesaid individual-cylinder control operation is usually accomplished by means of positioners, disposed in or on the cylinders, that are triggered by way of individual-cylinder control variables. These control variables are, for example, the triggering durations and/or triggering onsets of an injection.

The cylinder-pressure-based methods have the disadvantage that the measured values supplied by the pressure sensors are often erroneous as a result of tolerances related to manufacture and/or operation. If these measurement errors are not corrected, they distort the calculated cylinder pressure values and, because of the aforesaid control operation, result in mistuning among the individual cylinders.

The aforesaid measurement errors are expressed in differing sensor parameters that are preferably incorporated into sensor characteristic curves both as an erroneous offset and as an erroneous gain factor. Suggested solutions for calibrating or correcting the offset already exist, in which the pressure rise at the beginning of a compression phase of the internal combustion engine is evaluated. No methods so far exist,

however, for calibrating or correcting any erroneous gain factors. The individual gain factors moreover play a higher-order role in the overall operation of an internal combustion engine, since they are directly involved in the calculation of many other cylinder pressure features as well.

Object of The Invention

It is therefore the object of the present invention to make available a method, cited initially, for the calibration of sensors, disposed in at least two cylinders of an internal combustion engine operating in individual-cylinder fashion, for sensing a variable characterizing the combustion process in the respective cylinder, that makes possible adjustment of the at least two sensors with greater precision.

Advantages of The Invention

The aforesaid object is achieved by way of the features of the independent method claim. Advantageous embodiments are the subject matter of the dependent claims.

The method according to the present invention provides in a first step, in order to perform the aforesaid sensor adjustment, firstly for arriving at at least one operating point of the internal combustion engine in which an equalization of the cylinders in the aforesaid sense, using the fuel quantity equalization methods such as FQCC or SRC mentioned initially, is possible with relatively high precision. At this operating point, an equalization of the cylinders is then performed by means of at least one of the aforesaid fuel quantity equalization methods.

In an advantageous embodiment, the operating points of the internal combustion engine selected can be those in which only small disturbing side effects, such as the previously mentioned torsional vibrations of the crankshaft or unequal

combustion chamber/cylinder filling as a result of air mass fluctuations, are to be expected. One such preferred operating point is the idle mode.

The first step according to the present invention is based on the recognition that in the context of an equalization of the cylinders by means of an aforesaid fuel quantity equalization method, it can be assumed that all cylinders are receiving the same injection quantity and are therefore supplying the same torque or the same mean pressure.

In a second step, the equalization achieved in the first step is utilized in order to mutually adjust at least one of the aforesaid sensor parameters of at least two pressure sensors. This exploits the fact that the circumstances of the combustion process, preferably of the internal cylinder pressure (mean pressure) or torque, occurring in different cylinders in the first step during operation of the internal combustion engine are identical to a first approximation, and that discrepancies in the operating parameters of the internal combustion engine sensed respectively by the sensors thus derive, to a first approximation, exclusively from erroneous sensor parameters, in particular the gain factor and/or offset.

With the adjustment that can advantageously be performed during operation of the internal combustion engine, erroneous sensor parameters and characteristic curves can thus be corrected or calibrated in technically simple but nevertheless extremely efficient and precise fashion, thus effectively preventing any possible mistuning of the various cylinders of the internal combustion engine.

The relevant sensors here are preferably pressure sensors for sensing the internal cylinder pressure (mean pressure) occurring during combustion, and thus indirectly the torque indicated by the combustion.

The result is that by means of the method according to the present invention, the pressure profiles in the cylinders and the calculated operating parameters in the internal combustion engine are adapted to one another by correcting the gain factor and/or the offset of individual sensors. Although the method does not permit absolute calibration of the sensors, it does allow relative adjustment of the sensors to each other, yielding an overall improvement in the individual-cylinder operation of the internal combustion engine.

Drawing

The invention will be explained in more detail below with reference to the drawings and to preferred exemplary embodiments, from which further features and advantages of the invention are evident.

In the drawings:

Figure 1 shows a first exemplary embodiment of the calibration method according to the present invention with reference to a flow chart;

Figure 2 shows a second exemplary embodiment of the invention, once again with reference to a flow chart; and

Figure 3 shows sensor characteristic curves that are typically present after a cylinder equalization by means of FQCC/SRC in an internal combustion engine having four cylinders.

Description of The Exemplary Embodiments

Figure 1 shows a first exemplary embodiment of a routine according to the present invention for calibrating pressure sensors disposed in the cylinders (combustion chambers) of an

internal combustion engine (ICE) of a motor vehicle, with reference to which the basic concept of the invention is to be illustrated.

The routine shown starts with the ICE being transferred, in accordance with step 10, into an operating state in which very high cylinder equalization accuracy can be achieved by a fuel quantity compensation control system (FQCC) and/or a smooth-running control system (SRC). This transfer occurs, in a manner known per se, by an electronic engine control system. An operating state of this kind represents, in the present case, operation of the ICE at zero load at idle rotation speed (idle mode), since side effects disruptive to the FQCC and/or SRC, for example crankshaft torsional vibrations or air mass fluctuations, are minimized in this operating state.

In idle mode, according to step 12 an equalization of the individual cylinders of the ICE is then performed, in a manner known per se, by the FQCC and/or SRC. The result of this equalization is that all the cylinders deliver the same effective mean pressure pme. If the frictional mean pressure pmR is then considered, as a simplification, to be the same for all cylinders, the result is then, for all cylinders, the same indicated mean pressure pmi, which is made up of an effective mean pressure pme and the frictional mean pressure according to the equation pmi = pme + pmR, is then obtained for all cylinders. The indicated mean pressure pmi can moreover be calculated, in a manner known per se, from the respective cylinder pressure. Differences in the calculated pmi values of the various cylinders can therefore be attributed only to erroneous sensor characteristic curves, in particular to an erroneous gain factor. In addition, an offset of the sensor characteristic curves can also, at least in part, contribute to causing such a discrepancy.

It should be noted here that the correction of the offset value described initially and known per se in the existing art

is referred to the sensor characteristic curve U = f(p). In contrast thereto, the offset correction shown in Figure 3 refers to the characteristic curve of the parameters pmi = f(me). An offset error in the sensor characteristic curve U = f(p) has no effect on the calculated pmi value. Offset discrepancies in the characteristic curves pmi = f(me), on the other hand, are based not on sensor errors but on differences in mean frictional pressure, with the prerequisite than an ideal adjustment of the effective mean pressures can be performed, and that the aforesaid slopes have already been adjusted.

In the present exemplary embodiment, the cylinder pressure curves acquired in step 14 are themselves compared 16 and, using the result of that comparison, the individual sensor parameters are adjusted 18 to one another. Alternatively, other operating parameters of the ICE can also be used to adjust the sensor parameters/characteristic curves. As illustrated in Figure 2, the adjustment can also be performed by equating the aforesaid calculated pmi values.

It should be noted that in the exemplary embodiment described above, for technical simplification the adjustment is accomplished at only a single operating point of the ICE, whereas in the exemplifying embodiment depicted in Figure 2, at least two operating points must be arrived at. The latter variant nevertheless allows a higher calibration quality. In the exemplifying embodiment illustrated in Figure 1, however, a filtering operation, e.g. averaging over several operating cycles of the ICE, can additionally be provided in order to reduce the influence of stroke-to-stroke variations in the cylinders of the ICE.

Figure 2 depicts a second exemplifying embodiment in which the sensor characteristic curves are adjusted at several operating points of the ICE, i.e. in the present case at several loads at constant rotation speed. By taking into account the

aforesaid offset in the sensor characteristic curves, it is possible to take into account different frictional torques or frictional mean pressures pmR of the individual cylinders that are attributable, for example, to different compression conditions in the individual cylinders.

The procedure depicted in Figure 2 starts in step 100 with initiation of a counter n = 1. In step 102, the ICE is transferred into an n-th operating state, i.e. in the present case firstly into a first operating state. This first operating state is characterized by a load that depends on the injection quantity me at that operating point (me1) and by a rotation speed z that is hereafter assumed to be constant. At this first operating point of the ICE, in step 104 an equalization of the cylinders with one another by means of FQCC/SRC, as described with reference to Figure 1, is performed. Once the cylinders have been equalized, the pressures present in the cylinders are sensed 106 by the pressure sensors, and from the sensed pressure values, the torques or mean pressures pmi indicated respectively in the cylinders are calculated 108.

The number tuples (pmi, me) that now exist are then temporarily stored 110. The counter n is then incremented 112 by one and checked 114 to determine whether the incremented value of n is less than an upper limit n_max. Depending on the result of this comparison, execution either branches back to step 201 or proceeds further. The limit n_max thus defines how often the loop from 102 through 110 is repeated, i.e. how many different operating points of the ICE are arrived at (load A2 at me2, load A3 at me3, etc.) and how many of the aforementioned number tuples are stored.

If the upper limit n_max is exceeded, sensor characteristic curves (Figure 3) for the individual cylinders are prepared 116 from the temporarily stored number tuples (pmi, me). Compensation lines are adapted 118 to the individual

measurement points of the characteristic curves using the method of least error squares. In step 120, the slopes of these compensation lines are compared with one another, and respective discrepancies between them are calculated. If at least one of these discrepancies is greater than a threshold value that is to be ascertained empirically, then in the present exemplifying embodiment an error message 122 is outputted concerning the function of the sensor suite and/or of the ICE itself. Step 122 is merely optional.

If the assumption used here, to a first approximation, is a constant frictional torque or frictional mean pressure pmR in the individual cylinders, the sensor gain can then be interpreted as the slope of the compensation lines. What is obtained as the constant frictional torque or frictional mean pressure pmR is then the offset of the compensation lines for me = 0.

If the value is below the aforesaid threshold value, an adjustment of the sensor parameters can be accomplished. In step 124 the gain factors of the individual pressure sensors are adjusted to one another by adapting the slopes of the compensation lines. The curve or line adaptation 126 automatically, by the aforesaid offset of the compensation lines, also causes the frictional torques or frictional mean pressures of the cylinders to be adjusted to one another 126.

As an alternative to the linear function formulation pmi = f(me) described above for the sensor parameters, higher-order polynomial functions can also be taken as the basis. This allows consideration, in particular, of a frictional torque or frictional mean pressure pmR that changes with load.

In a further variant method not illustrated here, a plausibility check of the ascertained sensor parameters, in particular of the ascertained gain factors, is additionally performed. This makes it additionally possible, as in step 122

in Figure 2, to detect possible functional defects in one or more of the pressure sensors or even defects in the ICE itself, but with a higher quality as compared with Figure 2.

Lastly, Figure 3 shows the sensor characteristic curves typically obtained after a cylinder equalization by FQCC and SRC. Here the indicated torque or mean pressure pmi calculated from the pressure values sensed in each cylinder is plotted against the injection quantity me measured at three different operating points of the ICE. Compensation lines have already been adapted to the measurement points using the method of least error squares. The gain factor of the respective pressure sensors is derived directly from the slope of these lines. As is apparent, one of the three characteristic curves visibly deviates from the other characteristic curves in terms of its slope. It is precisely in the case of this line that an adjustment in accordance with the aforementioned method results in distinctly better calibration of the sensors with respect to one another.

It is understood that the fundamental concepts of the invention are applicable not only to ICEs having combustion chambers of cylindrical shape, but to ICEs of any kind, e.g. Wankel engines, having at least two combustion chambers. It is also understood here that the invention is usable not only in the context of the pressure sensors described above, but in principle with any sensors that are necessary for individual-cylinder operation of the ICE, i.e. suitable for sensing a variable that directly or indirectly characterizes the combustion process in the cylinders, for example injection quantity sensors or the like.